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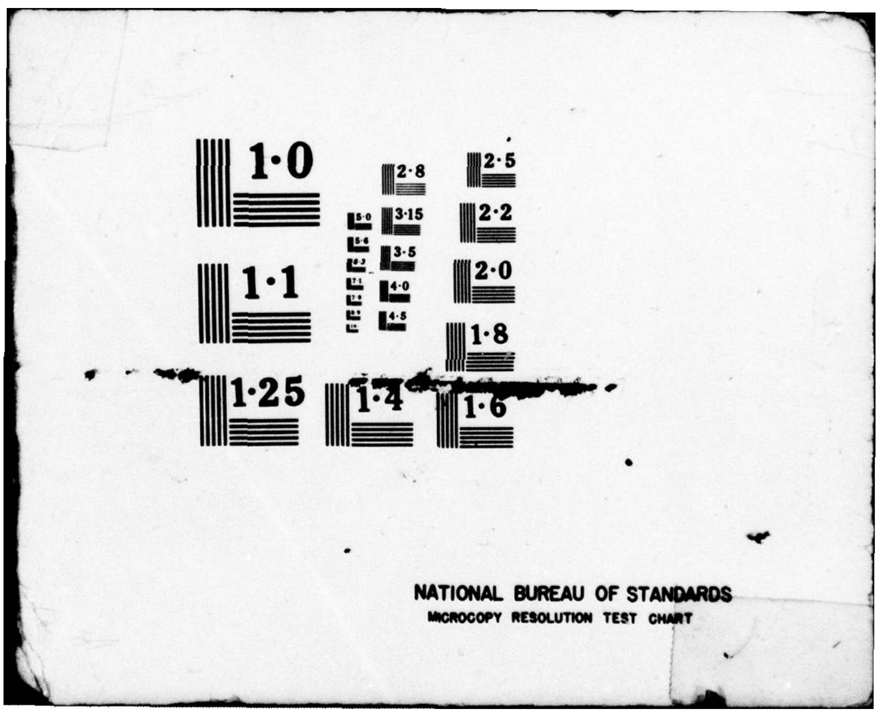
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DEGRADATION IN FLIR SENSITIVITY DUE TO

WINDOW ABSORPTANCE/EMITTANCE

AVIONICS ENGINEERING

PREPARED BY: Douglas W. Amlin
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Aeronautical Systems Division
Wright-Patterson AFB, OH 45433

MARCH 1979

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ABSTRACT

The degradation in the sensitivity of a FLIR as a result of the absorptance and emittance of the infrared window material is considered. An analytical treatment of the problem is presented along with some calculated results for the PAVE TACK system and three possible window materials.

I - INTRODUCTION

The PAVE TACK system currently utilizes a zinc sulfide window in conjunction with the AAQ-9 FLIR. There is some concern and speculation as to how much loss in sensitivity of the system is attributable to the window, and how much the sensitivity would be gained by the use of an improved window material such as gallium arsenide or zinc selenide. This report establishes a method of isolating the loss in system sensitivity due to the window and presents results for several window materials and conditions.

The theory behind this report is not new and calculations are similar to those made before. The uniqueness of the report is that effects of atmospheric transmittance/radiance are included as well as specific and current data on AAQ-9 system response and properties of three-window materials. The established methodology simplifies new calculations whenever new data becomes available or when additional trade studies are appropriate.

It should be noted that there are many factors which go into the selection of the best window material for a particular application. The loss in sensitivity due to a window must be considered along with strength, hardness, erosion resistance, solubility, coating adhesion, homogeneity, cost, producibility, etc. in making this selection.

This report was prepared by Douglas W. Amlin with considerable assistance from Ronald T. Vantrease and Roberto F. Soto, all personnel of the Imaging Systems Branch, Mission Avionics Division, Directorate of Avionics Engineering, Deputy for Engineering, Wright-Patterson Air Force Base, Ohio.

II - PURPOSE

The purpose of this paper is to calculate Sensitivity Reduction Factors (SRFs) for three different window materials; ZnS, ZnSe and GaAs. The PAVE TACK FLIR system with known relative spectral response in the 7.5 - 12.0 micron region is assumed. Results are presented which show how the SRF for each window material varies as a function of window temperature. In addition, atmospheric effects on SRF are presented based on atmospheric transmission and radiance factors computed for a variety of conditions.

III - BACKGROUND

Most airborne FLIR systems are used in conjunction with an infrared window which acts as a barrier between the FLIR and the dynamic environment in which the aircraft is operating. The infrared window is generally not perfectly transparent throughout the spectral bandpass of the FLIR and, consequently, affects the performance of the FLIR by a combination of absorption and emission of detectable radiation. It can be shown that the loss in thermal sensitivity induced by an IR window is proportional to the ratio of the Signal/Noise Ratio (SNR) with and without the window, $(SNR)_W/(SNR)_O$ or Sensitivity Reduction Factor (SRF). After making a few general assumptions, this factor can be calculated without further consideration of specific features of the sensor system under consideration.

It has been shown by Klein[1,2] that a "simple and elegant formalism exists for assessing the degradation in signal to noise ratio resulting from the presence of a partially transparent window at the entrance aperture of a FLIR sensor." The degradation involves a reduction in target signal and an increase in system noise or:

$$\frac{SNR_W}{SNR_O} = \frac{HEFF_W/HEFF_O}{NEI_W/NEI_O} \qquad (1)$$

$HEFF_W/HEFF_O$ is the ratio of effective signal irradiance with and without the window and is calculated from:

$$\frac{HEFF_W}{HEFF_O} = \frac{\int_{\lambda_1}^{\lambda_2} T(\lambda, T_w)\, W_\lambda(T_B)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} W_\lambda(T_B)\, d\lambda} \qquad (2)$$

NEI_W/NEI_O is the ratio of noise equivalent irradiance with and without the window and is calculated from:

$$\frac{NEI_W}{NEI_O} = \left[\frac{\int_{\lambda_1}^{\lambda_2} E(\lambda, T_w)\, Q_\lambda(T_w)\, d\lambda + \int_{\lambda_1}^{\lambda_2} T(\lambda, T_w)\, Q_\lambda(T_B)\, d\lambda}{\int_{\lambda_1}^{\lambda_2} Q_\lambda(T_B)\, d\lambda}\right]^{1/2} \qquad (3)$$

The individual terms in these equations are defined as follows:

$T(\lambda, T_w)$ = Transmittance of the window at a particular wavelength and temperature.

$W_\lambda(T_B)$ = Blackbody spectral radiant exitance evaluated at the temperature of the background.

$E(\lambda, T_w)$ = Emittance of the window at a particular wavelength and temperature.

$Q_\lambda(T_B)$ = Spectral quantum exitance function evaluated at the temperature of the background.

$Q_\lambda(T_w)$ = Spectral quantum exitance function evaluated at the temperature of the window.

The quantity SNR_w/SNR_O may properly be defined here as a sensitivity reduction factor (SRF) since the noise equivalent temperature (NET) of a system with a window can be defined as:

$$NET_w = \frac{SNR_O}{SNR_w} NET_O \tag{4}$$

or

$$NET_w = 1/SRF \; NET_O \tag{5}$$

Likewise, the minimum resolvable temperature (MRT) of a system at target spatial frequency (f_T) with a window can be calculated from:

$$MRT_w(f_T) = \frac{\tilde{\gamma}_w(f_T)}{SRF} MRT_O(f_T) \tag{6}$$

where $\tilde{\gamma}_w$ represents the window-related contribution to the modulation transfer function of the system and is obtained from:

$$\tilde{\gamma}_w(f_T) = \frac{MTF_w(f_T)}{MTF_O(f_T)} \tag{7}$$

Based on these equations, it is seen that the effect of a window on the sensitivity of a FLIR system can be reduced to a

single figure of merit:

$$SRF \equiv SNR_w/SNR_o \qquad (8)$$

This value can be calculated with very little knowledge of the specific features of the system. However, it should be noted that the foregoing assumes (1) that the window is at a uniform temperature and exhibits lambertian characteristics, (2) the detector package includes a cold shield which blocks all internal noise, (3) no absorption by the sensor optics or atmosphere and (4) a flat detector response throughout the spectral bandpass of the system.

IV - FORMULATION

In order to utilize the basic theory and equations of Klien to evaluate window degradation for a practical situation, two modifications can be made. First, a detector factor can be worked into the equations and secondly, the effect of the atmosphere can be taken into account. Without proper inclusion of these considerations, it is impossible to precisely isolate the effect of the window on system performance.

Inclusion of a detector factor into the equations presents little problem if the system response is known. A detector factor, $D(\lambda)$, must be inserted as a factor in each term of the equations for $HEFF_W/HEFF_O$ and NEI_W/NEI_O, and must include the relative response of the detector, the transmission of the system optics, and the transmission of the bandpass filter. Setting all values of $D(\lambda)$ equal to 1.0 is equivalent to disregarding the factor or "backing it out" of the calculation. Setting peripheral values of $D(\lambda)$ equal to zero is equivalent to setting the bandpass of the system.

Inclusion of atmospheric effects into the calculation is a bit more complicated. The effect of the atmosphere is analogous to the effect of the window; i.e., a loss of signal and an increase in noise. Values for atmospheric transmission, $A(\lambda)$, and values of atmospheric radiance, $R_\lambda(T_B)$, can be calculated by use of the LOWTRAN 4 computer program.[3] In this program $R_\lambda(T_B)$ includes the emission from the boundary (earth) at a specified temperature plus emission of the atmosphere for the specified slant range and weather conditions. Since the boundary is included in $R_\lambda(T_B)$, the quantity $Q_\lambda(T_B)$ in Equation (3) is no longer needed when $R_\lambda(T_B)$ is used. However, the units of $R_\lambda(T_B)$ must be changed from WATTS/cm^2-STER-micron to PHOTONS/cm^2-SEC-micron, $RQ_\lambda(T_B)$, to allow combination with $Q_\lambda(T_W)$, the noise coming from the window. Recalling that $Q_\lambda(T) = W_\lambda(T)\ \lambda/hc$, where "c" is speed of light and "h" is Planck's constant, it is seen that

$$RQ_\lambda(T_B) = 1.58 \times 10^{19}\ \lambda R_\lambda(T_B) \qquad (9)$$

Inclusion of detector and atmospheric factors into Equations (2) and (3) results in the following:

$$\frac{HEFF_W}{HEFF_O} = \frac{\int_{\lambda_1}^{\lambda_2} T(\lambda,T_w)\,D(\lambda)\,A(\lambda)\,W_\lambda(T_B)\,d\lambda}{\int_{\lambda_1}^{\lambda_2} D(\lambda)\,A(\lambda)\,W_\lambda(T_B)\,d\lambda} \tag{10}$$

$$\frac{NEI_W}{NEI_O} = \left[\frac{\int_{\lambda_1}^{\lambda_2} E(\lambda,T_w)\,D(\lambda)\,Q_\lambda(T_w)\,d\lambda + \int_{\lambda_1}^{\lambda_2} T(\lambda,T_w)\,D(\lambda)\,RQ_\lambda(T_B)\,d\lambda}{\int_{\lambda_1}^{\lambda_2} D(\lambda)\,RQ_\lambda(T_B)\,d\lambda}\right]^{1/2} \tag{11}$$

These are the integral forms of the equations for which a numerical solution was developed and adapted to the CDC 6600 Computer. A fortran program listing appears in the appendix. The solution in general requires inputs for .25 micron intervals of values of window transmittance and emittance, detector response, atmospheric radiance and transmission. Values of the blackbody function and the photon quantum exitance function are calculated internally.

V - INPUTS

A large number of variables is required to be input to LOWTRAN 4 for any calculation of atmospheric radiance and transmittance values. For purposes of this paper, four model atmospheres were chosen to allow simple presentation of the effect of different atmospheres on the SRF due to a window. The term "atmosphere" as used here includes operational scenario factors; i.e., altitude and slant range, as well as the basic intensive atmospheric properties. The four model atmospheres are:

MOD 1 • ATM (1) - 0.30KM Altitude, 6.06KM Slant Range, Visibility 3.00KM

MOD 2 • ATM (2) - 6.00KM Altitude, 9.09KM Slant Range, Visibility 3.00KM

MOD 3 • ATM (3) - 0.30KM Altitude, 15.25KM Slant Range, Visibility 10.00KM

MOD 4 • ATM (4) - 6.00KM Altitude, 15.25KM Slant Range, Visibility 10.00KM

All model atmospheres assume the midlatitude winter model, a final altitude of 0.03KM and a background temperature of 300°K. Transmittance and radiance values for these four models are presented in Table 1.

Three different window materials were considered. Transmittance and emittance values for each material are presented in Figure 2 and in Table 2 and are based on measured values reported recently under several government contracts. Some extrapolation was necessary to arrive at values for a window of appropriate thickness for PAVE TACK. The values are for anti-reflection coated windows, where reflection is either known to be or assumed to be on the order of 1.0 to 2.0 percent per surface. The values are not considered to be dependent on temperature (which is basically true); however, the temperature of the window is required as an input to the program since it is required in calculating photon noise from the window.

Values for Detector Factor, $D(\lambda)$, were obtained from Figure 1, the relative spectral response of the AN/AAQ-9 FLIR System, as recorded during laboratory testing. Values of $D(\lambda)$ read from Figure 1 in .25 micron increments from 7.0 to 13.0 microns are listed in Table 2.

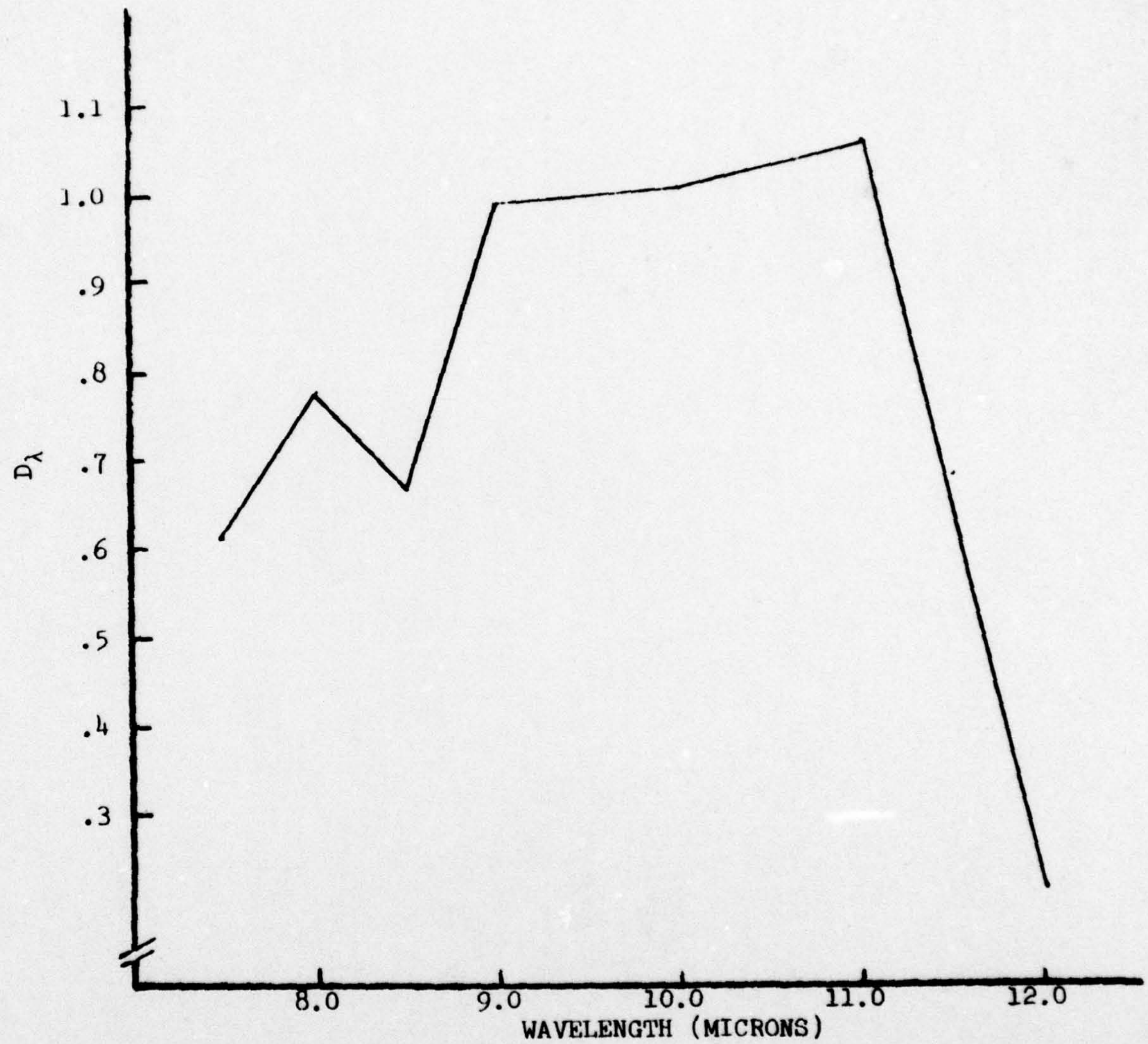

FIGURE 1

RELATIVE RESPONSE OF AAQ-9 FLIR

(Normalized at 10 Microns)

WAVELENGTH BAND (MICRONS)	TRANSMITTANCE MOD 1	MOD 2	MOD 3	MOD 4	RADIANCE (watts/cm^2-SR-micron) MOD 1	MOD 2	MOD 3	MOD 4
7.000 TO 7.250	0.000	.001	0.000	0.000	.316E-03	.210E-03	.328E-03	.200E-03
7.250 TO 7.500	.004	.026	.001	.009	.351E-03	.271E-03	.362E-03	.250E-03
7.500 TO 7.750	.039	.106	.008	.058	.398E-03	.352E-03	.398E-03	.316E-03
7.750 TO 8.000	.100	.208	.036	.141	.457E-03	.443E-03	.442E-03	.398E-03
8.000 TO 8.250	.333	.555	.223	.496	.594E-03	.679E-03	.558E-03	.647E-03
8.250 TO 8.500	.356	.645	.295	.631	.605E-03	.750E-03	.594E-03	.746E-03
8.500 TO 8.750	.333	.659	.308	.679	.566E-03	.761E-03	.583E-03	.783E-03
8.750 TO 9.000	.337	.688	.334	.722	.564E-03	.784E-03	.592E-03	.818E-03
9.000 TO 9.250	.321	.675	.318	.708	.573E-03	.790E-03	.601E-03	.821E-03
9.250 TO 9.500	.299	.584	.251	.564	.573E-03	.745E-03	.586E-03	.745E-03
9.500 TO 9.750	.320	.587	.258	.556	.579E-03	.748E-03	.590E-03	.743E-03
9.750 TO 10.000	.355	.644	.303	.629	.589E-03	.778E-03	.606E-03	.785E-03
10.000 TO 10.250	.396	.715	.360	.711	.601E-03	.812E-03	.625E-03	.835E-03
10.250 TO 10.500	.401	.721	.362	.733	.600E-03	.811E-03	.624E-03	.835E-03
10.500 TO 10.750	.421	.744	.381	.761	.600E-03	.814E-03	.626E-03	.842E-03
10.750 TO 11.000	.426	.751	.380	.766	.592E-03	.808E-03	.619E-03	.837E-03
11.000 TO 11.250	.428	.753	.376	.766	.587E-03	.800E-03	.613E-03	.828E-03
11.250 TO 11.500	.424	.747	.361	.755	.581E-03	.787E-03	.604E-03	.812E-03
11.500 TO 11.750	.405	.724	.328	.719	.572E-03	.766E-03	.589E-03	.785E-03
11.750 TO 12.000	.406	.722	.318	.714	.565E-03	.754E-03	.581E-03	.772E-03
12.000 TO 12.250	.391	.712	.299	.696	.556E-03	.738E-03	.570E-03	.752E-03
12.250 TO 12.500	.334	.626	.217	.586	.539E-03	.694E-03	.544E-03	.696E-03
12.500 TO 12.750	.305	.589	.182	.536	.527E-03	.669E-03	.530E-03	.665E-03
12.750 TO 13.000	.298	.568	.179	.530	.517E-03	.646E-03	.522E-03	.650E-03

TABLE 1

ATMOSPHERIC TRANSMITTANCE/RADIANCE VALUES FOR FOUR MODEL ATMOSPHERES IN .25 MICRON INTERVALS

	Transmittance			Emittance			Detector
WAVELENGTH BAND (MICRONS)	MAT 1	MAT 2	MAT 3	MAT 1	MAT 2	MAT 3	FACTOR
7.000 TO 7.250	.820	.900	.970	.148	.057	.005	0.000
7.250 TO 7.500	.845	.900	.970	.118	.057	.005	0.000
7.500 TO 7.750	.860	.920	.970	.093	.057	.005	.650
7.750 TO 8.000	.869	.920	.970	.073	.057	.005	.720
8.000 TO 8.250	.870	.920	.980	.073	.057	.005	.750
8.250 TO 8.500	.868	.920	.980	.078	.057	.005	.700
8.500 TO 8.750	.863	.920	.980	.083	.057	.005	.730
8.750 TO 9.000	.860	.920	.980	.103	.057	.005	.880
9.000 TO 9.250	.845	.920	.980	.113	.057	.005	.980
9.250 TO 9.500	.835	.920	.980	.113	.057	.005	.990
9.500 TO 9.750	.823	.920	.980	.113	.057	.005	1.000
9.750 TO 10.000	.810	.920	.980	.113	.057	.005	1.010
10.000 TO 10.250	.785	.920	.980	.113	.057	.005	1.020
10.250 TO 10.500	.730	.920	.980	.193	.057	.005	1.030
10.500 TO 10.750	.650	.920	.980	.253	.057	.005	1.030
10.750 TO 11.000	.550	.920	.980	.343	.057	.005	1.050
11.000 TO 11.250	.470	.920	.980	.403	.057	.005	.980
11.250 TO 11.500	.467	.920	.980	.413	.057	.005	.750
11.500 TO 11.750	.494	.910	.970	.393	.072	.005	.520
11.750 TO 12.000	.503	.910	.970	.373	.072	.005	.310
12.000 TO 12.250	.360	.900	.970	.383	.072	.005	0.000
12.250 TO 12.500	.285	.750	.970	.463	.222	.005	0.000
12.500 TO 12.750	.220	.750	.970	.563	.222	.005	0.000
12.750 TO 13.000	.171	.450	.970	.613	.513	.005	0.000

TABLE 2

TRANSMITTANCE AND EMITTANCE OF THREE WINDOW MATERIALS
AND AAQ-9 DETECTOR FACTOR IN .25 MICRON INTERVALS
MAT 1 - ZnS, MAT 2 = GaAs, MAT 3 = ZnSe

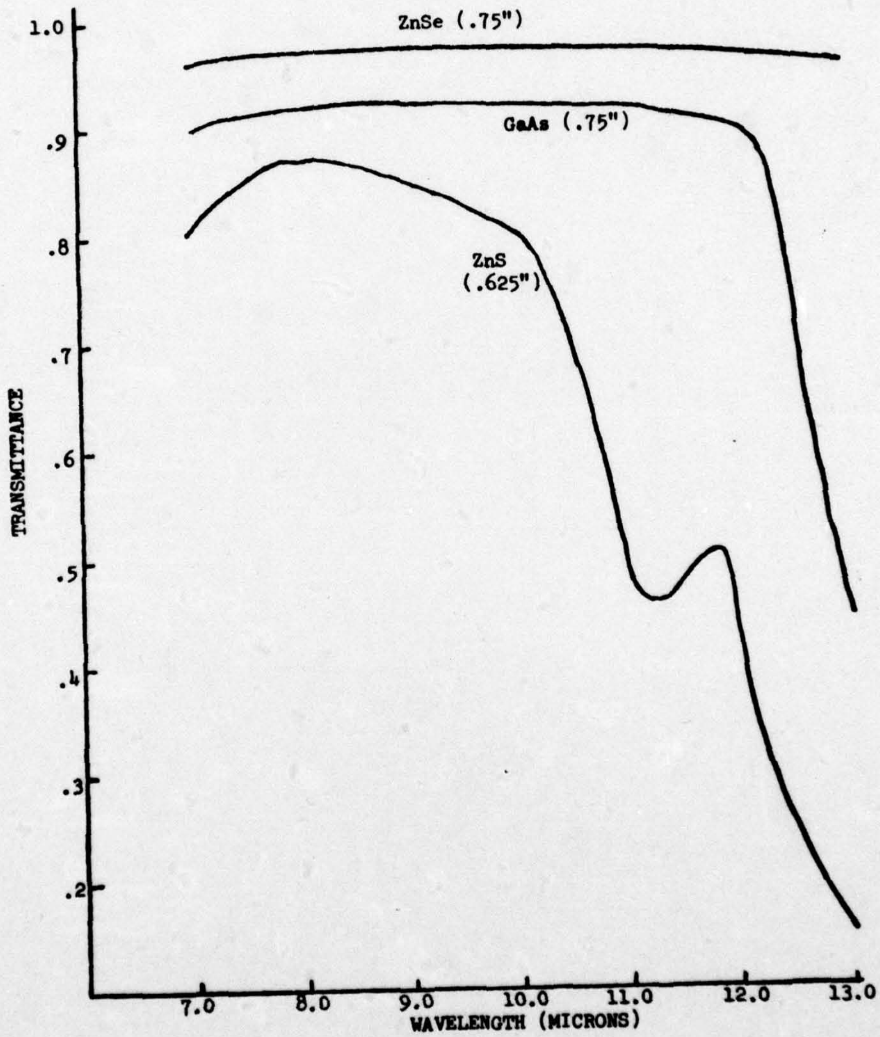

FIGURE 2

TRANSMITTANCE OF ANTI-REFLECTION COATED WINDOW MATERIALS

(Thicknesses Req'd For PAVE TACK)

VI - RESULTS

Table 3 presents the sensitivity reduction factors calculated for each of the window materials (at 300°K) and each of the model atmospheres. In all cases, the SRF for zinc sulfide is significantly less than for either zinc selenide or gallium arsenide. Due to the almost perfect transmittance of zinc selenide, the SRF for all conditions is almost constant. It should be understood, however, that system performance in terms of NET, MRT or other performance measure is not constant for different atmospheric models. A constant SRF means only that the window degrades the system performance by the same factor regardless of the atmosphere.

The values of SRF for atmospheres 1 and 3, and likewise 2 and 4, are nearly identical even for zinc sulfide because the spectral distribution of atmospheric transmittance and radiance is very similar for those models. Since atmospheric factors are present with and without the window, it is the spectral distribution, not the magnitude of these factors, which affects the calculation of SRF.

The effect of window temperature on the SRF for different window materials is clearly illustrated by Figure 3. As temperature increases, SRF decreases due to increased noise coming from the window. This effect is independent of the atmospheric model chosen.

Window Material	SRF: No Atmosphere	SRF: Atmosphere Model 1	2	3	4
Zinc Sulfide	.771	.698	.733	.701	.733
Gallium Arsenide	.930	.912	.922	.913	.923
Zinc Selenide	.987	.986	.986	.986	.987

TABLE 3

CALCULATED SENSITIVITY REDUCTION FACTORS
FOR WINDOW MATERIALS AT 300°K

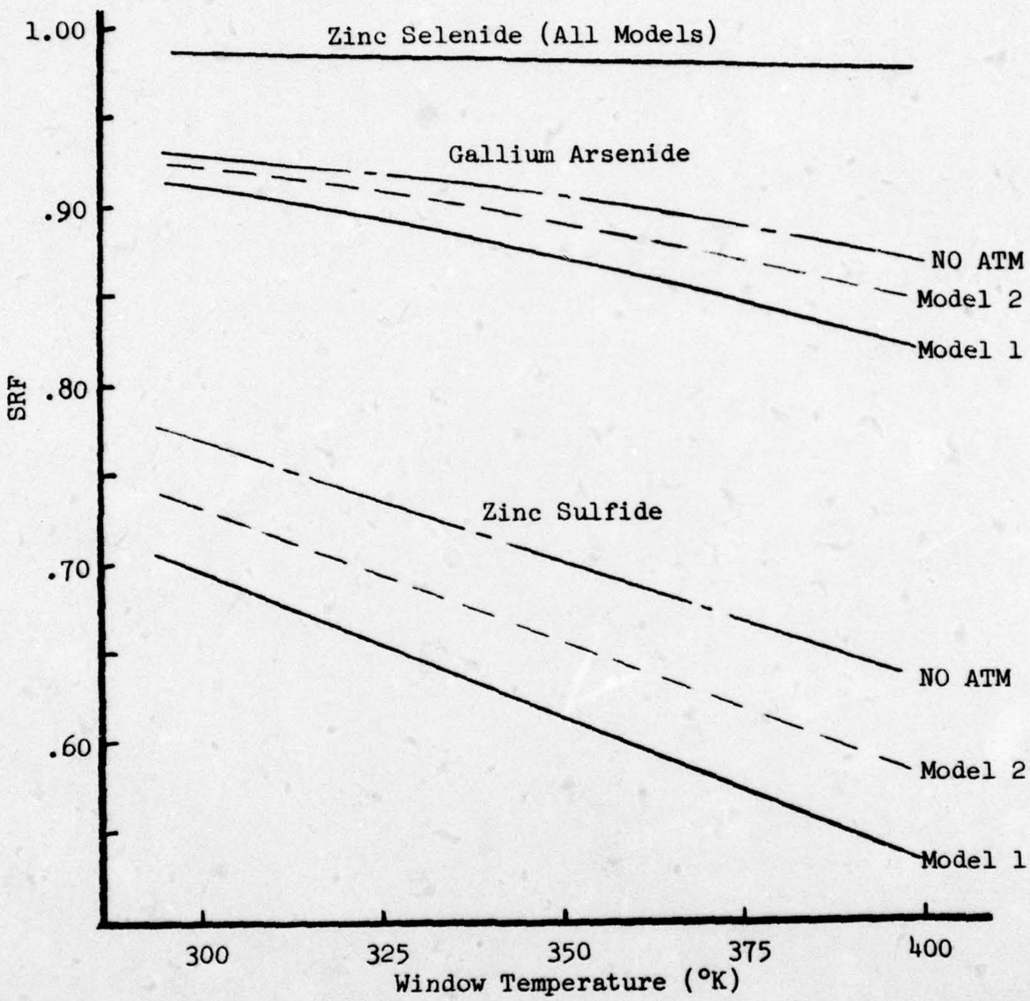

FIGURE 3

SENSITIVITY REDUCTION FACTOR AS A FUNCTION OF WINDOW TEMPERATURE FOR SEVERAL ATMOSPHERIC MODELS

VII - CONCLUSIONS

The use of a ZnS window in the PAVE TACK system results in a loss of sensitivity of 22 to 45% depending on window temperature and atmosphere.

The use of a GaAs window in PAVE TACK would result in only a 7 to 17% loss in sensitivity; a ZnSe window, virtually no loss.

VIII - REFERENCES

1. C. A. KLEIN, "FLIR Window Materials for Advanced Combat Aircraft: Their Impact on System Sensitivity," Proceedings of the 1976 IRIS Meeting on Infrared Imaging (ERIM, Ann Arbor, Michigan, June 1976), pp 37-52.

2. C. A. KLEIN, "CVD Zinc Sulfide Windows and FLIR System Performance," T-1022 Technical Memorandum from the Raytheon Company, Research Division, March 1977.

3. J. E. A. SELBY, Atmospheric Transmittance/Radiance: Computer Code LOWTRAN 4, AFGL-TR-78-0053, Hanscom AFB, Mass., 1978.

IX - APPENDIX


```
      PROGRAM SRFACT      74/74    OPT=1                    FTN 4.6+446       02/14/79  12.07.5

      PROGRAM SRFACT(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      DIMENSION QTB(24),QTW(24),W(24)
      DIMENSION D(24),A(24,4),R(24,4)
      DIMENSION SRF(3,4),T(24,3),E(24,3)
      INTEGER ATM,ATMAX
      REAL NEIO,NEIW,NEIR
      NAMELIST/TRANS/T
      NAMELIST/EMISS/E
      NAMELIST/DETEC/D
      NAMELIST/ATMOS/A,R
      WL1=7.0
      WLINC=.25
      IMAX=24
      TB=300.
      TWDOW=300.
      DELT=25.
C  T(I) AND E(I) ARE THE TRANSMISSIVITY AND EMISSIVITY OF THE WINDOW FOR
C WAVELENGTH INTERVAL(I)  THESE VALUES MUST BE INPUT
C  QTB(I) AND QTW(I) ARE THE PHOTON EMITTANCE FUNCTION EVALUATED FOR THE
C WAVELENGTH INTERVAL(I) AND AT THE TEMPERATURE OF THE BACKGROUND(TB) OR
CTEMPERATURE OF THE WINDOW (TWDOW).  THE VALUES ARE CALCULATED BY THE
C  SUBROUTINE PHOTON.
C W(I) IS THE BLACKBODY FUNCTION EVALUATED FOR THE WAVELENGTH INTERVAL(I
C TEMPERATURE OF THE BACKGROUND.
C     TB=TEMP OF BACKGROUND
C     WLINC= WIDTH OF EACH WAVELENGTH INCREMENT IN MICRONS.
      READ(5,TRANS)
      READ(5,EMISS)
      READ(5,DETEC)
      READ(5,ATMOS)

      ATMAX=1
      KMAX=1
      IF(T(12,2).NE.0.0)KMAX=2
      IF(T(12,3).NE.0.0)KMAX=3
      IF(A(12,2).NE.0.0)ATMAX=2
      IF(A(12,3).NE.0.0)ATMAX=3
      IF(A(12,4).NE.0.0)ATMAX=4

*  PRINT INPUT VALUES OF TRANSMITTANCE, EMITTANCE, AND DETECTOR FACTOR

      PRINT 106
      PRINT 107
      PRINT 108
      WLMIN=WL1
      DO 10 I=1,IMAX
      WLMAX=WLMIN+WLINC
      PRINT 110,WLMIN,WLMAX,(T(I,K),K=1,3),(E(I,J),J=1,3),D(I)
   10 WLMIN=WLMAX

*  PRINT INPUT VALUES OF ATMOSPHERIC TRANSMITTANCE AND RADIANCE

      PRINT 112
      PRINT 114
      WLMIN=WL1
      DO 12 I=1,IMAX
      WLMAX=WLMIN+WLINC
```

```
      PRINT 116,WLMIN,WLMAX,(A(I,J),J=1,4),(R(I,K),K=1,4)
   12 WLMIN=WLMAX

      DO 23 ITEMP=1,5

      WLMIN=WL1
      DO 25 I=1,IMAX
      WLMAX=WLMIN+WLINC
C
C   CALCULATE VALUES OF QTB FOR EACH WLINC. , IF RADIANCE VALUES FROM
C  LOWTRAN ARE INPUT, THESE VALUES OF QTB WILL NOT BE USED.
      CALL PHOTON(WLMIN,WLMAX,Q,JMAX,TB)
      QTB(I)=Q
C
C  CALCULATE VALUES OF QTW FOR EACH WLINC
      CALL PHOTON(WLMIN,WLMAX,Q,JMAX,TWDOW)
      QTW(I)=Q
C
C  CALCULATE VALUES OF W FOR EACH WLINC
      CALL BBODY(WLMIN,WLMAX,WBB,JMAX,TB)
      W(I)=WBB
   25 WLMIN=WLMAX

C
      DO 27 ATM=1,ATMAX
      IF(R(12,ATM).EQ.0.0) GO TO 29
      DO 28 I=1,IMAX
      (WLMIN=WL1)   WLMAX = WLMIN + WLINC
      QTB(I)=R(I,ATM)*(WLMIN+WLMAX)*.5*1.58E19*.26
   28 WLMIN=WLMAX
      GO TO 30
   29 PRINT*,"VALUES OF QTB ARE NOT FROM LOWTRAN"
C
C
*  COMPUTE HEFFW, HEFFO, NEIW, AND NEIO
C
   30 DO 31 K=1,KMAX
      HEFFW=0.0
      HEFFO=0.0
      NEIW=0.0
      NEIO=0.0
      DO 35 I=1,IMAX
      HEFFW=HEFFW+T(I,K)*A(I,ATM)*D(I)*W(I)
      HEFFO=HEFFO+A(I,ATM)*D(I)*W(I)
      NEIW=NEIW+E(I,K)*D(I)*QTW(I)+T(I,K)*D(I)*QTB(I)
   35 NEIO=NEIO+D(I)*QTB(I)
      NEIR=(NEIW/NEIO)**.5

   31 SRF(K,ATM)=(HEFFW/HEFFO)/NEIR
C
   27 CONTINUE
C

*
*
   40 PRINT 140,TB,TWDOW
      PRINT 145,((K,ATM,SRF(K,ATM),K=1,KMAX),ATM=1,ATMAX)

      PRINT*, "  "
   23 TWDOW=TWDOW+DELT
   60 STOP


  106 FORMAT(1H1,40X,*TABLE OF INPUT VALUES*)
  107 FORMAT(//,48X,*TRANSMITTANCE*,25X,*EMITTANCE*,13X,*DETECTOR*)
  108 FORMAT( 9X,*WAVELENGTH BAND (MICRONS)*,3X,*MAT 1*,7X,*MAT 2*,7X,*M
     CAT 3*,7X,*MAT 1*,7X,*MAT 2*,7X,*MAT 3*,7X,*FACTOR*)
  110 FORMAT(13X,F7.3,* TO*,F7.3,7F12.3)
  112 FORMAT(////,40X,*ATMOSPHERE FACTORS*,/)
  114 FORMAT(3X,*WAVELENGTH BAND (MICRONS)*,*TRANS     MOD 1*,7X,*MOD 2*7
     CX,*MOD 3*,7X,*MOD 4*,*  RAD MOD 1*,7X,*MOD 2*,7X,*MOD 3*,7X,*MOD 4
     C*,/)
  116 FORMAT(13X,F7.3,* TO*,F7.3,8F12.3)
  140 FORMAT(//,10X,*TB=*,F5.1,10X,*WINDOW TEMP=*,F5.1,2X,*DEGREES KELVI
     CN*)
  145 FORMAT(20X,*SRF(WINDOW*,I2,*,ATM MODEL*,I2,*)=*,F5.3)
C
      END
```

SUBROUTINE PHOTON 74/74 OPT=1 FTN 4.6+446 02/14/79 12.07.55

```
      C
            SUBROUTINE PHOTON(WLMIN,WLMAX,Q,JMAX,TEMP)
      C  ALL UNITS OF LENGTH ARE MICRONS, TEMP IS KELVIN
            DELWL=.01
            PI=3.1416
            C1=2.99776E14
            C2=1.436E4
            Q=0.
            JMAX=(WLMAX-WLMIN)/DELWL+.5
            WL=WLMIN
            C=2.*PI*C1
            QOLD=C/(WL**4.*(EXP(C2/(WL*TEMP))-1.))
            DO 20 J=1,JMAX
            WL=WL+DELWL
            QNEW=C/(WL**4.*(EXP(C2/(WL*TEMP))-1.))
            Q=Q+.5*(QNEW+QOLD)*DELWL
            QOLD=QNEW
         20 CONTINUE
      C  THE UNITS OF Q ARE NOW CHANGED FROM PHOTONS * MICRON**-2*SEC**-1 TO
      C     PHOTONS * CM**-2 * SEC**-1
      C
            Q=Q*1.E8
      C
            RETURN
            END
```

SUBROUTINE BBODY 74/74 OPT=1 FTN 4.6+446 02/14/79 12.07.55

```
            SUBROUTINE BBODY(WLMIN,WLMAX,WBB,JMAX,TEMP)
      C  ALL UNITS OF LENGTH ARE MICRONS, TEMP IS KELVIN
            DELWL=.01
            PI=3.1416
            C1=2.99776E14
            C2=1.436E4
            PH=6.626E-27
            C=2.*PI*C1**2.*PH
            WBB=0.0
            JMAX=(WLMAX-WLMIN)/DELWL+.5
            WL=WLMIN
            WOLD=C/(WL**5.*(EXP(C2/(WL*TEMP))-1.))
            DO 20 J=1,JMAX
            WL=WL+DELWL
            WNEW=C/(WL**5.*(EXP(C2/(WL*TEMP))-1.))
            WBB=WBB+.5*(WNEW+WOLD)*DELWL
            WOLD=WNEW
         20 CONTINUE
      C  THE UNITS OF WBB ARE NOW CHANGED FROM ERG/(SEC*MICRON**2) TO WATTS/CM
      C
            WBB=WBB*10.
      C
            RETURN
            END
```

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